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Joint Services Electronics Program
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April 15, 1987 - April 14, 1990

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TWO-DIMENSIONAL SIGNAL PROCESSING AND STORAGE
AND
THEORY AND APPLICATIONS OF ELECTROMAGNETIC
MEASUREMENTS

July 15, 1990

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
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This is an final report on research conducted under the auspices of the Joint Services Electronics Program. Specific topics covered are: digital signal processing, parallel processing architectures, two-dimensional optical storage and processing, hybrid optical/digital signal processing, electromagnetic measurements in the time domain, and automatic radiation measurements for near-field and far-field transformations.

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Two-Dimensional Signal Processing and Storage
and
Theory and Applications of
Electromagnetic Measurements

Joint Services Electronics Program
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April 15, 1987 to April 14, 1989

Final Report

Contents

1 Overview

This is the Final Report on research carried out under Contract DAAL-03-87-K00059. The research is part of the Joint Services Electronics Program (JSEP) and is administered by the U. S. Army Research Office. The report is concerned with basic research in the following broad areas of electronics:

- *Multidimensional Digital Signal Processing*
- *Optical Storage and Information Processing*
- *Electromagnetic Measurements*

The three year period covered by the contract has produced significant progress in all these areas. Some of the highlights of the research progress are given below for each area.

1.1 Progress in Multidimensional Digital Signal Processing Research

Research in the digital signal processing area has been concerned with representing multidimensional signals in digital form and processing such signals using digital computation. Specifically, the research in this area during the previous three years has been focused on signal modeling, algorithms for processing multidimensional signals, and optimal implementation of digital signal processing algorithms using multiprocessor architectures. Significant results have been obtained in iterative signal restoration, phase retrieval from Fourier transform magnitude, morphological system theory and applications, multilevel thresholding for image simplification, textured image segmentation, fractal models for texture, signal modeling and power spectrum estimation, signal modeling over non-uniform grids, minimum redundancy non-uniform sensor arrays, optimality conditions for multiprocessor implementations, scheduling algorithms (or compilers) for a variety of multiprocessor architectures, generation of systolic implementations from graph descriptions of algorithms, and construction of an experimental hardware multiprocessor (OSCAR-32). Some of the more noteworthy contributions are described briefly below.

- *Constrained Iterative Signal Restoration*
  Iterative techniques for solving signal restoration and estimation problems have been extensively investigated under JSEP sponsorship. In general, this research has shown how constraints on signal properties can be incorporated into the restoration or estimation algorithm to improve the quality of the output. Recent research has produced a new convex programming approach for optimal signal restoration and estimation with noisy signals. The new algorithms can incorporate prior knowledge of the signal in the form of bounds, and prior knowledge of

the noise in the form of power levels and the power density spectrum. A variety of cost criteria such as least squares, maximum entropy, and minimum cross entropy cost criteria can be applied, leading to algorithms whose performance criteria can be adapted to different classes of signals and distortions. Also, the maximum entropy and minimum cross entropy criteria have been modified to accommodate prior estimates of the unknown signal, thereby making them more reliable estimators for general signal restoration problems.

- *Morphological System Theory*
  A general theory of translation-invariant systems has been developed and applied under JSEP sponsorship. This theory significantly extends previous results in mathematical morphology and it unifies a wide range of commonly used image processing operations under a common framework. It was shown that any translation-invariant increasing system can be represented as a union of erosions by a set of system-specific characteristic structuring elements called the *kernel* of the system, and that this representation includes systems such as median filters, order-statistics filters, edge detectors, shape recognition transformations, and even a class of linear systems. The theory has already led to new insights and new implementations of such systems, and it figures prominently in current and proposed new research in developing a design methodology for morphological systems.

- *Periodic Scheduling Theory for DSP Multiprocessors*
  In work under JSEP sponsorship, three optimal periodic scheduling methods were developed: *skewed single instruction multiple data* (SSIMD), *cyclo-static*, and *Multi-Cyclic Instruction Multiple Data* (MCIMD). The latter is an extension of cyclo-static schedules based primarily on the use of heterogeneous processing elements. Recent work has resulted in the unification of SSIMD, cyclo-static and MCIMD as well as the more traditional scheduling methods of Critical Path Method (CPM), As Soon/Late As Possible (ASAP/ALAP), systolic array schedules, and static pipeline schedules. The new work has shown that all of these schedules can be represented in a single unified form based on a *period matrix* and a *cycling vector.* Furthermore, it has been shown how to transform a given schedule into any of the other classes of schedules. This unification is important because it shows that the generalized SSIMD schedule is the optimal class for homogeneous processors and that generalized *parallel SSIMD* (PSSIMD) is the optimal class for heterogeneous processors. This powerful conceptual framework has already led to a simplified representation of schedules and a corresponding simplification of the scheduling algorithm. Based on this result, a preliminary, general purpose, parallel processing architecture based on a low order chorded ring has been proposed.

1.2 Progress in Optical Storage and Information Processing Research

Research in this area aims to develop broadly-based theoretical and experimental knowledge of two-dimensional optical and hybrid optical/electronic information processing including algorithms, architectures, systems, and devices. During the past three years, many new and significant results have been obtained in areas such as antireflection grating surfaces, VLSI-compatible ferroelectric spatial light modulators, integrated optical implementation of matrix operations, electron wave optics in semiconductors, architectures for optical digital computation, rigorous coupled-wave theory of grating diffraction, optical implementation of morphological systems, partially coherent optical systems, three-dimensional image processing, dimensional mappings in optical signal processing, and bipolar incoherent spatial filtering. Details of some of the notable accomplishments are given below.

- *Zero-Reflectivity Surface Relief Gratings on Lossy Materials*
  The thickness and complex refractive index of single homogeneous layers on lossy substrates that are required to produce zero reflectivity have been calculated by a rigorous impedance matching approach. The analysis is applicable to both TE and TM polarization and to any angle of incidence. The method permits the filling factor and the groove depth of a rectangular-groove grating equivalent to a single homogeneous lossy layer in the long wavelength limit to be calculated. The method reduces to that previously found for dielectric surface-relief gratings in the limit of no losses. The anti-reflection behavior has been verified for the gratings using the rigorous (without approximations) coupled-wave analysis of metallic surface-relief grating diffraction. Multiple zero-reflectivity solutions exist for both TE and TM polarizations and for any angle of incidence for an arbitrary complex-refractive-index substrate. The theory has been verified experimentally through fabrication of zero-reflectivity gold gratings for an incident freespace wavelength in the range from $\delta_0 = 0.44\mu m$ to $12.0\mu m$. For the longer wavelengths, the behavior of the gold approaches that of a perfect conductor and the required filling factor approaches zero for TE polarization and unity for TM polarization.

- *Electron Wave Optics in Semiconductors*
  Starting from fundamental principles, quantitative analogies between quantum mechanical electron waves in semiconductor materials and electromagnetic optical waves in dielectrics have been developed. These analogies make it possible to apply much of the already existing electromagnetic theory and design methodology directly to the development of many new classes of electron wave optical devices such as narrow-band superlattice interference filters. Possible new electron wave devices include low pass filters, high pass filters, notch filters (narrow band and wide band), bandpass filters (narrow band and wide band), impedance transformers (antireflection coatings), and high reflectance surfaces (dielectric mirrors).

These electron wave filter devices can have Butterworth (maximally flat), Chebyshev, elliptic function, or other type of characteristics. Narrow band filters can be incorporated monolithically into transistor structures in order to increase their speed. Pumping a superlattice resonant cavity gives rise to the possibility of a coherent electron wave amplifier and/or emitter. These are all one-dimensional quantum well type devices. Two-dimensional and three-dimensional devices such as beamsplitters, cylindrical lenses, spherical lenses, and diffraction gratings are also possible using quantum wire and quantum box structures. These devices could assist in the control of freespace electron beams in fields such as electron spectroscopy, electron beam lithography, and electron diffraction analysis of crystals.

- *Silicon VLSI-Compatible Ferroelectric Liquid Crystal Light Modulators*
  A procedure has been developed for fabricating most components of a reflective surface-stabilized ferroelectric liquid crystal light modulator cell into unmodified CMOS processing. This is a key prerequisite for the development of optically interconnected VLSI and wafer-scale systems. The existence of a light modulator technology compatible with logic circuit technology will enable the unconstrained placement of a large number of logic-driven light sources on a die or wafer. Several prototype arrays have been fabricated and tested.

- *Optical Morphological Transformations and Extensions*
  Optical techniques for implementation of morphological operations (e.g., erosion and dilation) have been combined with time-sequential threshold decomposition in an experimental demonstration of nonlinear image filtering. Recently, a novel modification of the basic morphological transformation method using a gray-scale structuring element rather than the normal binary structuring element was demonstrated. This work is significant because it allows certain impulsive noise removal operations to be performed in half as many steps.

1.3 Progress in Electromagnetic Measurements Research

Research in this area seeks to develop new methodology for making electromagnetic measurements directly in the time domain or over a wide bandwidth in the frequency domain, and to develop new understanding of the near-field and far-field coupling between antennas in the presence of scatterers. Specifically, JSEP-supported research during the past three years has yielded new knowledge concerning materials for electromagnetic scale models, ground penetrating radars, pulse excited antennas, millimeter wave substrate-mounted antennas, radome anomaly detection, shaped serrated diffraction fence theory and design, and spectral evaluation of reflector surfaces in compact antenna ranges. The following paragraphs give more details on some of these contributions.

- *Materials for Electromagnetic Scale Models*
  In this research, simple emulsions were examined as materials with adjustable electrical constitutive parameters. These emulsions are mixtures of oil, saline solution, and a suitable stabilizing agent (emulsifier). Since the relative permittivities of oil and water are around two and eighty, respectively, a large range of permittivity can be obtained for the emulsions. The conductivity of the emulsions can be adjusted by changing the normality of the saline solution. A series of oil-in-water emulsions (oil droplets in water), suitable for use in scale models, was developed; this includes the selection of an appropriate emulsifier. The electrical constitutive parameters of these emulsions are adjustable over wide ranges and are predictable from a simple formula. The emulsions should be particularly useful for representing geophysical materials in models for buried antennas, subsurface radars, etc.

- *Radome Anomaly Detection Using Spherical Near-Field Measurement*
  A theory and technique have been developed, implemented, and tested for the non-invasive, high accuracy determination of radome wall performance. The technique, which involves the backward propagation of the measured spherical surface fields surrounding the radome, has a demonstrated spatial resolution of better than one-half wavelength. The demonstrated high accuracy and resolution of the technique could lead to an order of magnitude improvement in radome electromagnetic performance.

- *Shaped Edge Serrations for Improved Reflector Performance*
  A new edge treatment for electromagnetic reflectors has been developed that produces less wide angle scattering than previously used edge treatments. The new edge treatment allows a wide variety of field transition functions to be realized in an average sense. This new technology has been applied to the design of an improved compact antenna range reflector, resulting in a lower cost, better quiet zone performance range. This range is currently under construction at Ft. Huachuca, Arizona. This technology is currently being applied to the design and construction of a paraboloidal reflector antenna to achieve low, wide angle, sidelobe levels.

The remainder of this report provides a list of the individual work units and their principal investigators, a list of the doctoral degrees awarded during the three year period of the contract, and lists of publications produced by each of the work units. The annual reports for each of the individual contract years give more details of research results.

2 Work Units and Principal Investigators

Work Unit One: *Multidimensional Digital Signal Processing*
Principal Investigators: Russell M. Mersereau, Regents' Professor and Rockwell Fellow, and Monson H. Hayes, Associate Professor

Work Unit Two: *Representation, Coding and Analysis of Images*
Principal Investigators: Ronald W. Schafer, Regents' Professor, and Russell M. Mersereau, Regents' Professor and Rockwell Fellow

Work Unit Three: *Multiprocessors for Digital Signal Processing*
Principal Investigator: Thomas P. Barnwell, III, Professor and Rockwell Fellow

Work Unit Four: *Two-Dimensional Optical Information Processing*
Principal Investigators: Thomas K. Gaylord, Regents' Professor

Work Unit Five: *Two-Dimensional Optical/Electronic Signal Processing*
Principal Investigator: William T. Rhodes, Professor

Work Unit Six: *Electromagnetic Measurements in the Time and Frequency Domains*
Principal Investigator: Glenn S. Smith, Regents' Professor

Work Unit Seven: *Automated Measurements for Near- and Far-Field Transformations*
Principal Investigator: Edward B. Joy, Professor

Work Unit Eight: *Angular Spectrum Analysis for Non-Uniform Arrays*
Principal Investigator: James H. McClellan, Professor

3 Doctoral Degrees Awarded

James E. Bevington - Ph.D., December 1987
Thesis: *A Statistical Model-Based Approach to Textured Image Segmentation*

André Knoesen - Ph.D., May 1987
Thesis: *Guided Modes in Anisotropic Dielectric Planar Waveguides*

Elias N. Glytsis - Ph.D., November 1987
Thesis: *Interdigitated Electrodes and Anisotropic Diffraction Analysis of Phase and/or Lossy Gratings for Bulk and Integrated Applications*

R. Steve Weis - Ph.D., December 1987
Thesis: *Electromagnetic Transmission and Reflection Characteristics of Anisotropic Multilayered Structures*

C. Auyeung - Ph.D., December 1988
Thesis: *Optimal Constraint-Based Signal Restoration and its Applications*

H. R. Forren - Ph.D., May 1988
Thesis: *Multiprocessor Design Methodology for Real Time Digital Signal Processing Systems Represented by Shift Invariant Flow Graphs*

Timothy J. Drabik - Ph.D., March 1990
Thesis: *Optically Interconnected Parallel Processor Arrays*

4 Publications

4.1 Work Unit One: Multidimensional Digital Signal Processing

Theses:

1. C. Auyeung, *Optimal constraint-based signal restoration and its applications*, Ph.D. Thesis, *Georgia Institute of Technology*, September 1988.

Other Publications:

1. C. E. Morris, M. A. Richards and M H. Hayes, "Iterative deconvolution algorithm with quadratic convergence," *Optical Society of America A*, vol. 4, page 200, January 1987.

2. E. Karlsson and M. H. Hayes, "Least squares ARMA modeling of linear time-varying systems: lattice filter structures and fast RLS algorithms", *IEEE Transactions on Acoustics, Speech and Signal Processing*, vol. ASSP-35, no. 7, pp. 994-1014, July 1987.

3. R. L. Lagendijk, J. Biemond and R. M. Mersereau, "On increasing the convergence rate of regularized iterative image restoration algorithms," *Proc. 1987 IEEE International Conference on Acoustics, Systems and Signal Processing*, pp. 1183-1186, April 1987.

4. C. E. Morris, M. A. Richards, and M. H. Hayes, "A generalized fast iterative deconvolution algorithm," *Proc. 1987 International Conference on Acoustics, Speech and Signal Processing*, pp. 1553-1556, April 1987.

5. D. M. Thomas and M. H. Hayes, "A novel data-adaptive power spectrum estimation technique," *Proc. 1987 International Conference on Acoustics, Speech and Signal Processing*, pp. 1589-1592, April 1987.

6. E. Karlsson and M. H. Hayes, "Performance analysis of new least squares ARMA lattice modeling algorithms", *Proc. 1987 International Conference on Acoustics, Speech and Signal Processing*, pp. 984-987, April 1987.

7. D. M. Wilkes and M. H. Hayes, "An eigenvalue recursion for Toeplitz matrices," *IEEE Trans. on Acoustics, Speech, and Signal Processing*, vol. ASSP-35, no. 6, pp. 907-909, June 1987.

8. M. H. Hayes, D. M. Wilkes, and M. A. Clements, "Iterative harmonic decomposition of nonstationary random processes: Theory and application to spectral line tracking," *Mathematics in Signal Processing*, T. S. Durrani et. al., Editors, pp. 105-119, Clarendon Press, Oxford, 1987.

9. R. M. Mersereau, Z. Shen and M. H. Hayes, "Selection of ideal filters for the window design method," *Signal Processing IV*, (Lacoume et al, editors), North Holland, 1988.

10. R. M. Mersereau, Z. Shen, and M. H. Hayes, "Effect of ideal transition specification on window designs," *IEEE ASSP Digital Signal Processing Workshop*, September 1988.

11. C. S. Kim, J. Bruder, M. J. T. Smith and R. M. Mersereau, "Subband coding of color images using finite state vector quantization," *ICASSP 1988*, pp. 753-756.

12. D. M. Wilkes and M. H. Hayes, "Iterated Toeplitz approximation of covariance matrices," *Proceedings Int. Conf. on Acoustics, Speech, and Signal Processing*, pp. 1663-1666, April 1988.

13. C. E. Morris, M. A. Richards, and M. H. Hayes, "Fast restoration of linearly distorted signals," *IEEE Trans. on Acoustics, Speech, and Signal Processing*, vol. ASSP-36, no. 7, pp. 1017-1025, July 1988.

14. D. M. Wilkes and M. H. Hayes, "Block Toeplitz approximation," *Signal Processing*, vol. 15, no. 3, pp.303-313, October 1988.

15. M. H. Hayes, D. S. Mazel, and D. M. Wilkes, "2-D constrained harmonic retrieval," *Proc. Twenty-second Asilomar Conference on Signals, Systems, and Computers*, pp. 762-766, Asilomar, CA, November 1988.

16. C. Auyeung and R. M. Mersereau, "A dual approach to signal restoration," *Proc. 1989 International Conference on Acoustics, Speech and Signal Processing*, pp. 1326-1329, Glasgow, Scotland, May, 1989.

17. C. Auyeung and R. M. Mersereau, "Efficient algorithms for least squares restoration," *SPIE Conference on Visual Communication and Image Processing IV*, pp. 1534-1540, 1989.

18. W.S. Kim and M.H. Hayes, "Phase retrieval using two Fourier transform intensities," *Proc. Opt. Soc. Am. Topical Conf. on Signal Recovery*, pp. 138-141, Cape Cod, June 1989.

19. W. Kim and M. H. Hayes, "Phase retrieval using two Fourier intensities," *Proc. 1990 Int. Conf. on Acoustics, Speech, and Signal Processing*, pp. 1563-1566, April 1990.

20. W. S. Kim and M. H. Hayes, "Phase retrieval using two Fourier transform intensities," *Journal Optical Society of America: A*, Special Issue on Signal Recovery, vol. 7, no. 3, pp. 441-449, March 1990.

4.2 Work Unit Two: Representation, Coding, and Analysis of Images

Theses:

1. J. E. Bevington, "A statistical model-based approach to textured image segmentation," Ph.D. Thesis, *Georgia Institute of Technology, School of Electrical Engineering*, November, 1987.

Other Publications:

1. P. A. Maragos and R. W. Schafer, "Morphological filters - part I: their set-theoretic analysis and relations to linear shift-invariant filters," *IEEE Trans. Acoustics, Speech, and Signal Processing*, vol. ASSP-35, pp. 1153-1169, Aug. 1987.

2. P. A. Maragos and R. W. Schafer, "Morphological filters - part II: their relations to median, order-statistic, and stack filters," *IEEE Trans. Acoustics, Speech, and Signal Processing*, vol. ASSP-35, pp. 1170-1184, Aug. 1987.

3. J. E. Bevington and R. M. Mersereau, "Differential operator based edge and line detection," *Proceedings of the International Conference on Acoustics, Speech and Signal Processing*, vol. 1, pp. 249-252, Dallas, Texas, April, 1987.

4. C. H. Richardson and R. W. Schafer, "Application of mathematical morphology to FLIR images," *Proc. of SPIE, Visual Communications and Image Processing*, vol. 845, Cambridge, MA, Oct. 1987.

5. Lois Hertz and R. W. Schafer, "Multilevel thresholding using edge matching," *Computer Vision, Graphics and Image Processing*, vol. 44, pp. 279-295, 1988.

6. P. A. Maragos, "A representation theory for morphological image and signal processing," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 11, pp. 586-599, June, 1989.

7. D. Y. Suh, R. M. Mersereau, R. L. Eisner, and R. I. Pettigrew, "Knowledge-based boundary detection applied to cardiac magnetic resonance image sequences," *Proc. 1989 International Conference on Acoustics, Speech and Signal Processing*, vol. 3, pp. 1783-1786, Glasgow, Scotland, May, 1989.

4.3 Work Unit Three: Multiprocessors for Digital Signal Processing

Theses:

1. H. R. Forren, "Multiprocessor design methodology for real time digital signal processing systems represented by shift invariant flow graphs" Ph.D. Thesis, *Georgia Institute of Technology*, Atlanta, Georgia, May, 1988.

Books or Chapters in Books:

1. D. A. Schwartz, "Cyclo-static realizations, loop unrolling and CPM: optimal multiprocessor scheduling," *Concurrent Computations (Algorithms, Architecture and Technology*, Chapter 16, Published by Plenum Press, New York, 1988. Articles published based on an invited presentation at the 1987 Princeton Workshop on Algorithm, Architecture and Technology Issues for Models of Concurrent Computation, September 30-October 1, 1987, Princeton University, Princeton, New Jersey.

Other Publications:

1. H. F. Forren and D. A. Schwartz, "Transforming periodic synchronous multiprocessor programs," *Proc. of the International Conference on Acoustics, Speech and Signal Processing*, Dallas, TX, April, 1987.

2. S. J. A. McGrath, T. P. Barnwell III and D. A. Schwartz, "A WE-DSP-32 based, low cost multiprocessor for cyclo-static implementations," *Proc. of the International Conference on Acoustics, Speech and Signal Processing*, Dallas, TX, April, 1987.

3. K. Nayebi, T. P. Barnwell III, and M. J. T. Smith, "Time domain conditions for exact reconstruction in analysis/synthesis systems based on maximally decimated filter banks," *1987 Southeast Symposium on System Theory*, Clemson, SC, March, 1987.

4. S. H. Lee and T. P. Barnwell III, "Optimal multiprocessor implementations from non-parallel algorithm specifications," *1988 International Conference on Acoustics, Speech, and Signal Processing*, New York, NY, April, 1988.

5. L. P. Heck, D. A. Schwartz, R. M. Mersereau, and J. H. McClellan, "Symbolic simplification of digital signal processing software," *Proc. 1989 Intern. Symp. on Circuits and Systems*, Portland, OR, May, 1989.

6. S. J. A. McGrath, C. P. Hong and T. P. Barnwell III, "A scheduling methodology for a synchronous cyclo-static multiprocessor," *1989 International Conference on Systolic Processors*, Killarny, Ireland, May 1989.

4.4 Work Unit Four: Two-Dimensional Optical Information Processing

Theses:

1. André Knoesen, "Guided modes in anisotropic dielectric planar waveguides," Ph.D. Thesis, *Georgia Institute of Technology*, Atlanta, Georgia, May 1987.

2. Elias N. Glytsis, "Interdigitated electrodes and anisotropic diffraction analysis of phase and/or lossy gratings for bulk and integrated applications," Ph.D. Thesis, *Georgia Institute of Technology*, Atlanta, Georgia, November 1987.

3. R. Steve Weis, "Electromagnetic transmission and reflection characteristics of anisotropic multilayered structures," Ph.D. Thesis, *Georgia Institute of Technology*, Atlanta, Georgia, December 1987.

4. Timothy J. Drabik, "Optically interconnected parallel processor arrays," Ph.D. Thesis, *Georgia Institute of Technology*, Atlanta, Georgia, March 1990.

Other Publications:

1. E. N. Glytsis, T. K. Gaylord, and M. G. Moharam, "Electric field, permittivity, and strain distributions induced by interdigitated electrodes on electro-optic waveguides," *Journal of Lightwave Technology*, vol. LT-5, pp. 668-683, May 1987.

2. M. M. Mirsalehi and T. K. Gaylord, "Residue number systems in content-addressable memory processing," *Proceedings SPIE*, vol. 752, pp. 175-178, 1987.

3. T. K. Gaylord and E. I. Verriest, "Matrix triangularization using arrays of integrated Givens rotation devices," *Computer*, vol. 20, pp. 59-66, December 1987. (invited)

4. T. K. Gaylord, E. N. Glytsis and M. G. Moharam, "Zero-reflectivity homogeneous layers and high spatial-frequency surface-relief gratings in lossy materials," *Applied Optics*, vol. 26, pp. 3123-3135, August 1, 1987.

5. E. N. Glytsis and T. K. Gaylord, "Rigorous three-dimensional coupled-wave diffraction analysis of single and cascaded anisotropic gratings," *Journal of the Optical Society of America A*, vol. 4, pp. 2061-2080, November 1987.

6. R. S. Weis, and T. K. Gaylord, "Electromagnetic transmission and reflection characteristics of anisotropic multilayered structures," *Journal of the Optical Society of America A*, vol. 4, pp. 1720-1740, September 1987.

7. A. Knoesen, N. F. Hartman, T. K. Gaylord and C. C. Guest, "Minicomputer interface for magneto-optic spatial light modulator," *Review of Scientific Instruments*, vol. 58, pp. 1843-1851, October 1987.

8. T. K. Gaylord and A. Knoesen, "Passive integrated optical anisotropy-based devices," *Journal of Modern Optics*, vol. 35, no. 6, pp. 925-946, 1988.

9. R. S. Weis and T. K. Gaylord, "Fabry-Perot/Šolc filter with distributed Bragg reflectors: A narrow-band electro-optically tunable spectra filter," *Journal of the Optical Society of America A*, vol. 5, pp. 1565-1570, September 1988.

10. N. F. Hartman and T. K. Gaylord, "Antireflection gold surface-relief gratings: experimental characteristics," *Applied Optics*, vol. 27, pp. 3738-3743, September 1988.

11. E. N. Glytsis and T. K. Gaylord, "Antireflection surface structure: dielectric layer(s) over a high spatial-frequency surface-relief grating on a lossy substrate," *Applied Optics*, vol. 27, pp. 4288-4304, October 1988.

12. E. N. Glytsis and T. K. Gaylord, "Anisotropic guided-wave diffraction by interdigitated electrode-induced phase gratings," *Applied Optics*, vol. 27, pp. 5031-5050, December 1988.

13. T. K. Gaylord and K. F. Brennan, "Semiconductor superlattice electron wave interference filters," *Appl. Phys. Lett.* vol. 53, pp. 2047-2049, November 1988.

14. T. A. Maldonado and T. K. Gaylord, "Electrooptic effect calculations: simplified procedure for arbitrary cases," *Applied Optics*, vol. 27, page 5051-5066, December 1988.

15. A. Knoesen, T. K. Gaylord and M. G. Moharam, "Hybrid guided modes in uniaxial dielectric planar waveguides," *Journal of Lightwave Technology*, vol. 6, no. 6, pp. 1083-1104, June 1988.

16. M. M. Mirsalehi, T. K. Gaylord, D. C. Fielder, and C. C. Guest, "Number representation effects in truth table look-up processing: 8-bit addition example," *Appl. Opt.*, vol. 28, pp. 1931-1939, May 15, 1989.

17. R. S. Weis and T. K. Gaylord, "Magneto-optic multilayered memory structure with a birefringent superstrate: A rigorous analysis," *Appl. Opt.*, vol. 28, pp. 1926-1929, May 15, 1989.

18. T. A. Maldonado and T. K. Gaylord, "Accurate method to determine the eigenstates of polarization in gyrotropic media," *Appl. Opt.*, vol. 28, pp. 2075-2086, June 1, 1989.

19. E. N. Glytsis and T. K. Gaylord, "Rigorous three-dimensional coupled-wave diffraction analysis of multiple superposed anisotropic gratings," *Appl. Opt.*, vol. 28, pp. 2401-2421, June 15, 1989.

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